Oct. 17, 1967 JAMES E. WEBB 3,347,665
ADMINISTRATOR OF THE NATIONAL AERONAUTICS
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LOW TEMPERATURE ALUMINUM ALLOY

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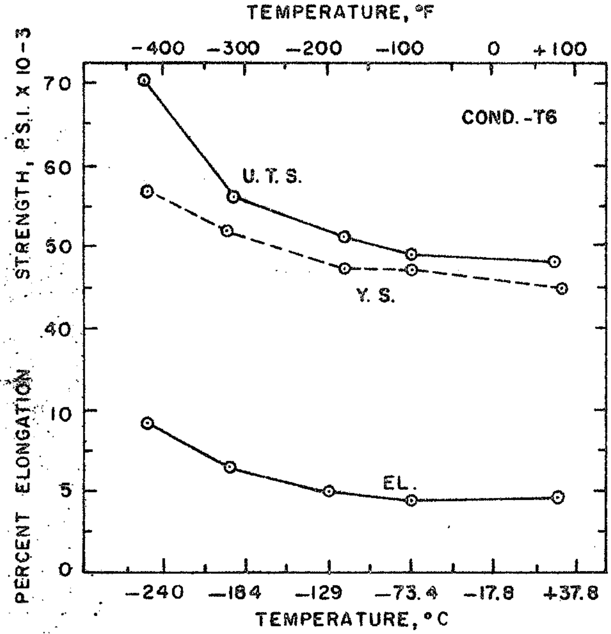

FIG. 1

LOW TEMPERATURE MECHANICAL PROPERTIES OF NEW ALLOY

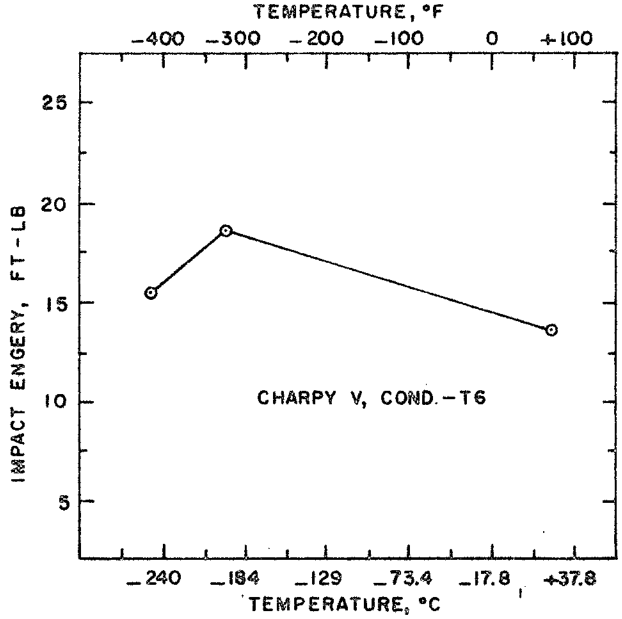

FIG. 2

IMPACT ENERGY OF NEW ALLOY

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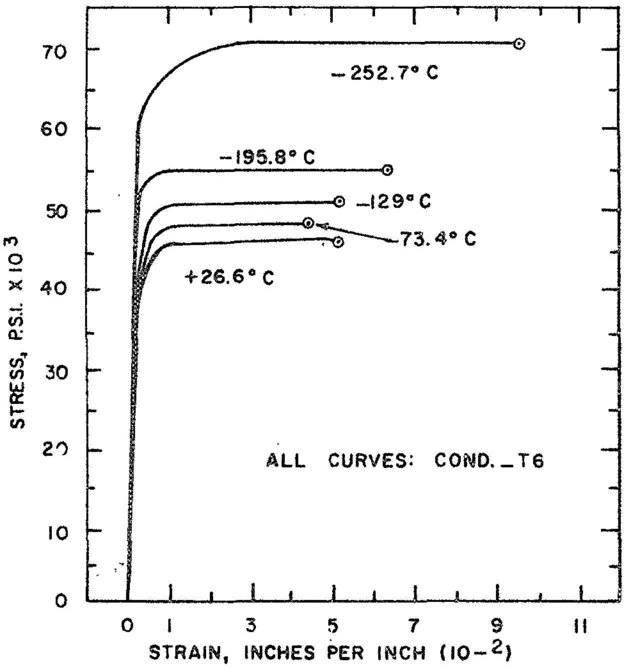
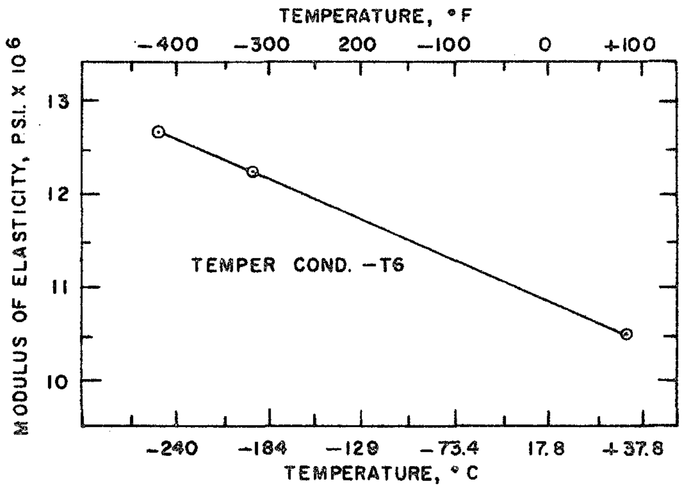


STRESS − STRAIN DIAGRAMS OF A NEW ALLOY

FIG. 3



MODULUS OF ELASTICITY OF A NEW ALLOY

FIG. 4

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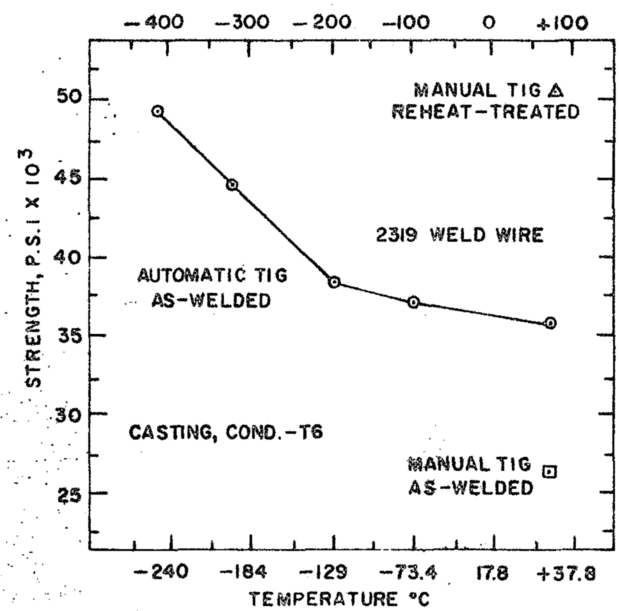
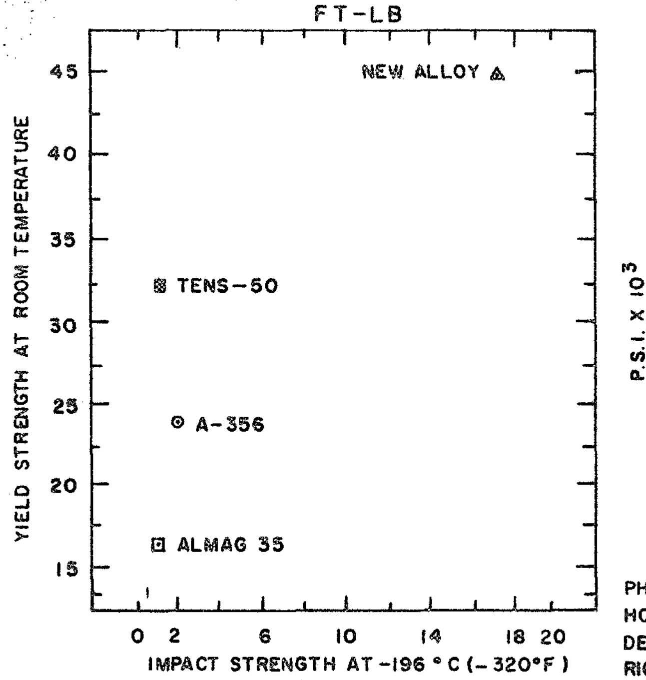


WELD STRENGTHS OF A NEW ALLOY

FIG. 5



COMPARISON OF MECHANICAL PROPERTIES OF SEVERAL ALUMINUM ALLOYS

FIG. 6

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3,347,665

LOW TEMPERATURE ALUMINUM ALLOY

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6 Claims. (Cl. 75—142)

ABSTRACT OF THE DISCLOSURE

An aluminum casting alloy having the following composition in weight percent: copper, 3.90 to 4.50; cadmium, 0.08 to 0.12; magnesium, 0.06 to 0.10; titanium, 0.02 to 0.05; and the balance aluminum, the maximum total content of silicon, iron, chromium, manganese, vanadium and zinc impurities being 0.029 weight percent. This alloy exhibits high strength and toughness at extremely low temperatures so that it is particularly suitable for cryogenic applications in the aerospace field.

This invention relates generally to an aluminum base alloy and more particularly to an alloy which is especially adapted to be used in the casting of aluminum components or products for missiles, rockets and other types of space vehicles.

At the present time, space vehicles are using propellants which are in the form of liquefied gases. These gases become liquefied into desirable propellants at certain cryogenic temperature. For example, liquid oxygen and hydrogen propellants are formed at the low temperatures of approximately −297.4° F. and −423° F., respectively. Many of the structural components used on space vehicles are constructed from light-weight, aluminum alloys which must come in contact with these liquid propellants and, accordingly, resist impact or otherwise withstand high stresses at extremely low temperatures. Heretofore, it has been necessary to construct these components by forging the aluminum alloys in order to meet the high quality standards which have been set for materials to be used in space flight hardware.

Although the components formed heretofore from forged aluminum alloys have proven satisfactory to a certain degree, they are not deemed suitable where construction and maintenance cost must be kept to a minimum. Aluminum forgings and welded structures, which are very costly and usually require extensive machining, have been used in many instances where an aluminum casting would be ideal. However, there are no commercial aluminum alloys available at the present time which can be cast into a component or product and still be capable of withstanding the high stresses normally encountered at extremely low temperatures when used on a rocket or missile.

In accordance with the present invention, a new aluminum alloy has been discovered which overcomes the difficulties and disadvantages heretofore encountered with the use of commercially available aluminum alloys in cryogenic applications. Intensive research has shown that an excellent casting alloy can be produced for effective use at low temperatures by utilizing a super purity aluminum base with copper in the amount of 3.90% to 4.50% by weight constituting the principal strengthening additive, and cadmium, magnesium and titanium in the total amount of 0.16% to 0.27% added to improve on the ductility and toughness. The presence of cadmium in the casting alloy has been found to increase considerably the yield and ultimate strengths when used in the amount of 0.08% to 0.12%. Based upon the mechanical property results produced during an investigation of a number of alloy additions, it has been determined that when the magnesium and titanium contents exceeded 0.1% and 0.05%, respectively, the toughness of the casting alloy at cryogenic temperatures is reduced significantly. However, desirable low temperature properties of the casting alloy result when both magnesium and titanium are added in amounts of 0.06% to 0.10% and 0.02% to 0.05%, respectively. It has also been found that the presence of impurities such as iron, silicon, chromium, manganese, vanadium, and zinc, does have a detrimental affect on the casting alloy. Therefore, a practical maximum limit of 0.029% has been established for the sum total of these undesirable alloy additions. As a result of these findings from the intensifying research conducted, the new alloy of the present invention has been developed for use in the casting of high quality components or products to be subjected to extremely low temperatures. The specific tests and analyses of this new casting alloy as well as the chemical composition thereof will be discussed in detail hereinafter.

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Accordingly, it is an object of the present invention to provide a new casting alloy which is especially adapted for use at cryogenic temperatures.

It is also an object of this invention to provide a new casting alloy with strength and impact resistance properties which surpass those of commercially available casting alloys heretofore used at low temperatures.

Another object of the present invention is to provide a new aluminum casting alloy which exhibits excellent workability, castability, weldability, strength, toughness, response to heat treatment and compatibility with other alloys.

A further object of this invention is to provide a new casting alloy which results in a considerable saving of time, manpower and cost in the manufacture of components for use on rockets and missiles.

Other objects and advantages of this invention will become more apparent from a reading of the following detailed description and appended claims taken in conjunction with the accompanying drawing wherein:

FIGURE 1 is a graph showing the ultimate tensile strength, yield strength and percent of elongation of the new alloy at various temperatures.

FIGURE 2 is a graph showing the impact energy of the new alloy at various temperatures.

FIGURE 3 is a graph showing the stress and strain values for the new alloy at various temperatures.

FIGURE 4 is a graph showing the modulus of elasticity of the new alloy at various temperatures.

FIGURE 5 is a graph showing the weld strengths of the new alloy at various temperatures.

FIGURE 6 is a graph showing a comparison of the mechanical properties of the new alloy with those of commerical alloys.

The present invention comprises a new alloy designated as M45 which weighs approximately 0.0995 pound per cubic inch and falls within the following composition range by percentage of weight:

	Percent
Copper	3.90 to 4.50
Cadmium	0.08 to 0.12
Magnesium	0.06 to 0.10
Titanium	0.02 to 0.05
Silicon Iron Chromium Manganese Vanadium Zinc	[1] 0.029
Aluminum	Balance

[1] Maximum total.

A preferred alloy within the composition range set forth has the following specific composition:

	Percent
Copper	3.96
Cadmium	0.089
Magnesium	0.09
Titanium	0.048
Silicon, Iron, Chromium, Manganese, Vanadium, Zinc	[1] 0.029
Aluminum	Balance

[1] Maximum total.

The new alloy of this invention may be prepared by using well known methods and techniques. For example, the new alloy may be prepared by using the following technique:

(1) Mix—65% virgin metal, 35% remelt,

(2) Crucible—Clay graphite,

(3) Furnace—Pit type coke fired,

(4) Melt removed from furnace at 1400°–1425° F. and placed in vacuum chamber. Vacuum at 20 mm. for 6–7 minutes. Remove from vacuum and hold for pouring temperature,

(5) Pouring temperatures range between 1275° to 1350° F. depending on the size and wall thickness of the casting. Skim (with graphite tool) and pour into sand cast.

Test specimens of the new alloy have been so prepared and heat treated to the standard T6 temper in the following manner:

(1) Solution anneal 16 hours at 960° F. to 1000° F.,

(2) Quench in water at 50° F. to 150° F., and

(3) Age for 16 hours at 325° F.

An investigation has been undertaken to evaluate the characteristics of these test specimens to show that the new alloy satisfies the requirements of high strength and toughness for cryogenic applications in rockets and missiles. In this investigation, the tensile strength characteristics of the specimens test were evaluated at temperatures of 26.7° C. (80° F.), −73.4° C. (−100° F.), −129° C. (−200° F.), −196° C. (−320° F.), and −252.7° C. (−423° F.). The impact strengths of the test specimens were determined at 26.7° C. (80° F.), −196° C. (−320° F.), and −252.7° C. (−423° F.). In addition, tensile tests were made from 26.7° C. (80° F.) to −252.7° C. (−423° F.) on casting-to-plate weldments and at ambient temperature on casting-to-casting weldments.

For the tensile tests at cryogenic temperatures, specially constructed cryostats and extensometer adapters were used with test procedures developed for these temperatures. Charpy V notch impact tests were also conducted on the new alloy specimens at liquid nitrogen and liquid hydrogen temperatures with a standard impact testing machine. The impact specimen holding fixture was precooled with liquid nitrogen before testing was started. The new alloy specimens were also immersed in liquid nitrogen and allowed to stabilize at the temperature of the liquid nitrogen before being transferred to the testing machine. Liquid helium was used in the tests to simulate the liquid hydrogen temperature and was supplied from a 50 liter dewar through a vacuum jacketed transfer tube when the solenoid valve associate therewith was energized. A copper-constanton thermocouple which contacted the impact test specimen under spring tension just below the point of impact permitted an accuracy of the specimen temperature at impact of ±1° C. (±1.8° F.).

The new alloy test specimen for the cryogenic mechanical properties determination of the casting-to-plate weldments were made by welding the broken impact test specimens to ⅜-inch thick plate of 2219–T87 aluminum. The materials to be welded were chemically cleaned and the joint surfaces were hand scraped to remove excessive

oxides before welding. The casting specimens and 2219–T87 aluminum plate were squarely butted and clamped in place on a standard grooved copper backup bar. The joint was welded on each side thereof by using a 1/16-inch diameter filler wire of 2319 aluminum in the standard automatic TIG welding process. Other test specimens made from two sections of castings machined for a square butt joint were also evaluated at room temperature. The joint surfaces of these test specimens were prepared in a manner similar to that used for the casting-to-plate joint and the joint was welded on only one side thereof by using 3/32-inch diameter filler wire of 2319 aluminum.

TABLE I.—LOW TEMPERATURE MECHANICAL PROPERTIES OF NEW ALLOY

Temperature		Ultimate Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Percentage of Elongation
° C.	° F.			
+26.7	+80	47,700	44,700	5.0
−73.4	−100	49,600	47,600	4.3
−129.0	−200	50,900	47,700	5.1
−196.0	−320	56,600	52,400	6.4
−252.7	−423	70,600	56,900	9.4

Table I above sets forth data pertaining to the average ultimate tensile strength, yield strength, and percentage of elongation of the new alloy specimens tested at the various low temperatures. With reference to Table I and the diagram shown in FIG. 1 of the drawing, it is readily seen that the ultimate tensile strength and yield strength of the new alloy increased with a decrease in temperature. The ultimate tensile strength increased from 47,700 p.s.i. to 70,600 p.s.i. as the temperature decreased from +26.7° C. (+80° F.) to −252.7° C. (−423° F.). Likewise, the yield strength increased from 44,700 p.s.i. to 56,900 p.s.i. as the temperature decreased from +26.7° C. (+80° F.) to −252.7° C. (−423° F.). The percentage of elongation of the new alloy did not change appreciably at the temperatures between +26.7° C. (+80° F.) and −129.0° C. (−200° F.). However, there was a significant increase of 6.4% to 9.4% in the elongation when the temperature decreased from −196.0° C. (−320° F.) to −252.7° C. (−423° F.).

TABLE II.—LOW TEMPERATURE CHARPY V-NOTCH IMPACT PROPERTIES OF NEW ALLOY

Temperature		Charpy Impact Properties, ft.-lb.
° C.	° F.	
+26.7	+80	13.6
−196.0	−320	18.6
−252.7	−423	15.5

As shown in Table II above and FIG. 2 of the drawing, the impact strength of the new alloy test specimens increased to a maximum value of 18.6 ft.-lb. at −196.9° C. (−320° F.) and then decreased slightly to 15.5 ft.-lb. at −252.7° C. (−423° F.). However, even at −252.7° C. (−423° F.) the impact strength value remainder higher than that of 13.6 ft.-lb. at the ambient temperature of +26.7° C. (+80° F.). Accordingly, the results of the testing clearly showed that at low temperatures the new alloy is superior in toughness to most commercially available alloys.

Typical stress-strain and modulus of elasticity graphs for the new alloy tested at temperatures ranging from ambient to liquid hydrogen (−423° F.) are shown in FIGS. 3 and 4, respectively. The curves represent average values of the new alloy specimens in the standard T6 temper condition. These two graphs clearly show that the new alloy will withstand more stress and strain as the temperature decreases.

TABLE III.—LOW TEMPERATURE WELD STRENGTHS OF NEW ALLOY JOINED TO 2219–T87 PLATE

Temperature		Ultimate Tensile Strength, p.s.i.
° C.	° F.	
+26.7	+80	36,200
−73.4	−100	37,700
−129.0	−200	38,500
−196.0	−320	43,500
−252.7	−423	49,400

The weld strengths at low temperatures of the new alloy casting welded to a ⅜-inch plate of aluminum alloy 219–T87 are shown in Table III and FIG. 5. The new alloy casting was welded to the ⅜-inch plate by using a filler wire of 2319 aluminum in an automatic TIG welding process. The average strength of the automatic TIG weldments at the ambient temperature of +26.7° C. (+80° F.) was 36,200 p.s.i. and increased with decreasing temperature. A significant increase of weld strength was observed in the temperature range of −129° C. (−200° F.) to −252.7° C. (−4.23° F.) with average values at these two temperatures being 38,500 p.s.i. and 49,400 p.s.i., respectively.

The weld strengths at the ambient temperature of +26.7° C. (+80° F.) for test specimens of castings welded to castings are also shown in FIG. 5. The average strength was 25,700 p.s.i. in the as-welded condition. However, with a reheat treatment of (1) 40 hours at 1000° F., (2) water quenched and (3) 16 hours at 325° F., the weld strength of the welded test specimen increased to a value of 49,700 p.s.i., also double the weld strength of the test specimen in the as-welded condition. This result has been attributed to the fact that the hardness of the castings, originally Rockwell B72 to B76, was reduced to an average value of Rockwell B29.5 by the extended time at the elevated temperature which is inherent in the manual TIG welding process.

Micrographs (not shown) were also made of the new casting alloy which revealed large grains of various shapes with a discontinuous network of microconstituents along the grain boundaries. Dispersal of $CuAl_2$ particles occurred randomly throughout the matrix and grain boundaries. Dislocations were also apparent in some of the grains but such were attributed to internal stresses introduced during the tensile loading. The micrographs also showed extremely coarse grain texture and complete absence of columnar or dendritic structure, which are typical characteristics of the new casting alloy.

The yield strength and impact properties of the new alloy have also been compared with those of three commercially available alloys which are currently being used in space vehicles, Tens—50, A356 and Almag 35, to illustrate the differences in properties among the various types of aluminum alloy castings at cryogenic temperatures. Data for this comparison resulted from previous investigations and experimental work supplementary to the early programs related to the development of the new alloy of the present invention. This comparison was

made on the average yield strength at room temperature and on the impact strength at liquid nitrogen temperature (−320° F.) of these aluminum alloys which were sand cast without chills and heat treated, with the exception of Almag 35, which is normally a nonheat-treatable alloy. As shown in FIG. 6, the new alloy was markedly superior in tensile yield strength and toughness, as measured by impact strength at −196° C. (−320° F.), than the other three commercial aluminum alloys.

To those having experience in the art relating to the casting of aluminum alloys, it can be readily seen from the above description that the new casting alloy of the present invention has excellent mechanical properties and characteristics for use in the manufacture of rocket and missile components which are subjected to extremely low temperatures. It is to be understood, however, that the use of the new alloy is not limited to the manufacture of rocket and missile components or other products subjected to low temperatures but may obviously be used at any temperature to make or fabricate any type or kind of product.

Obviously numerous modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be further understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described and illustrated.

What is claimed is:

1. A casting alloy consisting essentially of from 3.90 to 4.50% of copper, from 0.08 to 0.12% of cadmium, from 0.06 to 0.10% of magnesium, and from 0.02 to 0.05% of titanium, the balance being aluminum.

2. An aluminum base alloy consisting essentially of 3.96% copper, 0.089% cadmium, 0.09% magnesium, and 0.048% titanium, the balance being aluminum.

3. An aluminum base alloy consisting essentially of 3.90% copper, 0.08% cadmium, 0.06% magnesium, and 0.02% titanium, the balance being aluminum.

4. An aluminum base alloy consisting essentially of 4.50% copper, 0.12% cadmium, 0.10% magnesium, and 0.05% titanium, the balance being aluminum.

5. An alloy consisting of 3.90 to 4.50% copper, 0.08 to 0.12% cadmium, 0.06 to 0.10% magnesium, 0.02 to 0.05% titanium, a maximum combined total of 0.029% of silicon, iron, chromium, manganese, vanadium, and zinc, the balance being aluminum, said alloy in cast form being characterized by superior yield strength, tensile strength and toughness at cryogenic temperatures.

6. A casting alloy consisting essentially of 3.96% copper, 0.089% cadmium, 0.09% magnesium, 0.048% titanium, and a combined total of about 0.029% of silicon, iron, chromium, manganese, vanadium, and zinc, the balance being aluminum.

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